SYSTEMS ENGINEERING
Research Center

SE Capstone: A Pilot Study of 14 Universities to Explore SE Learning and Career Interest through DoD Problems

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Abstract

This paper describes a research study whose goal is to understand the impact on student learning of and career interest in Systems Engineering (SE) through a set of diverse pilot SE capstone experiences being implemented in eight civilian universities and six military academies. The strategic goal addressed by this research is to explore how differing course designs, structures and materials impact student learning and career interest in SE in order to augment the SE workforce for future Department of Defense (DoD) and related industry workforce needs. A work-in-progress, this research outlines the rationale, research methods, approaches to course organization, structure, and delivery used across 14 diverse institutions with SE departments at approximately the mid-point of course delivery.

Program Rationale

A 45% growth is expected in SE jobs in the next decade[1] and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the SE workforce. The July 2006 National Defense Industrial Association (NDIA) Task Force noted among the top five SE issues the lack of adequate, qualified SE human capital resources within government and industry for allocation on major programs[2]. In the July 2010 NDIA white paper on critical SE challenges, Issue 2 was identified as: *The quantity and quality of SE expertise is insufficient to meet the demands of the government and defense industry*, and further outlined certain recommendations to build SE expertise and capacity. In particular, it recommended developing SE expertise through "role definition, selection, training, career incentives, and broadening 'systems thinking' into other disciplines," and made a number of specific recommendations, including adding an introductory course in SE in all undergraduate engineering and technical management degree programs; and working with major universities to recommend SE curricula to improve consistency across programs in order to achieve standardization of skill sets for graduates[3].

Research Objectives and Program Goals

Research on Building Education & Workforce Capacity in Systems Engineering, (referred to as the SE Capstone Project), aims to understand the methods through which SE learning and career interest may be increased among undergraduate and graduate engineering students. The key research question this program is designed to address is:

What organization of course work (course sequence, course materials, faculty characteristics, student characteristics) leads to the largest student gains in (1) SE learning; (2) interest in SE careers; and (3) interest in DoD problems and careers?

This research is being conducted in the context of 14 "capstone" courses, in most cases as an integrative culminating, project-based course involving teams of students working together on the development of a product or prototype that addresses a real Department of Defense (DoD)

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14. ABSTRACT
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need. Implemented as pilot courses in eight civilian and six military universities, most of which are members of a SE-focused University Advanced Research Center, or UARC based at Stevens Institute of Technology), these 14 institutions are piloting methods, materials, and approaches to create new courses or enhance existing courses to embed, infuse, and augment SE knowledge, as defined by the Systems Planning, Research Development, and Engineering (SPRDE)-SE and Program Systems Engineer (PSE) competency model, known as the SPRDE-SE/PSE Competency Model, among undergraduate and graduate students. Participating university faculty developed new course materials and other methods and strategies to recruit and provide substantive SE learning experiences; increase exposure to authentic DoD problems, such as low-cost, low-power computing devices, expeditionary assistance kits, expeditionary housing systems, and immersive training technologies.

These 14 piloting universities are implementing methods and approaches hypothesized to lead to increased student interest in SE education and careers, particularly in DoD and related industry contexts. This pilot program is being conducted in order to inform the development of a national scale-up effort that would substantially expand the number and capabilities of universities that could produce SE graduates needed for the DoD and related defense industry workforce. It is anticipated that the implementation of the pilot courses will lead to the discovery of exemplary course materials, assessment instruments, and other lessons that will be deployed to accelerate the adoption of effective practices and materials in a national scale up. An analysis of effective practices based on the experience of the 14 universities, along with recommendations for national scale-up, will result from this research.

Literature Review

With the increased focus on science and engineering education from elementary through higher education since the launching of the Sputnik[4], the number of undergraduate and graduate SE degree programs offered in the United States over the past 50 years has reached 165 programs across 80 institutions[5]. However, the best methods and approaches for developing SE curriculum continue to evolve as the discipline evolves[6-9]. In the past decade, in an effort to address workforce development needs in SE, separate competency models for SE have been developed by individual companies, consortia, and professional societies. Descriptions and comparisons of these models are available from a variety of sources[10-12]. Over the last few years, one such model development took place in the defense acquisition community. Subject matter experts developed and validated the SPRDE-SE/PSE. The SPRDE-SE/PSE competency model is comprised of twenty-nine areas of competencies grouped according to three primary "units of competences" – analytical, technical management, and professional – as shown in Table 1[13]. The analytical unit covers thirteen competencies related to the technical base for cost and aspects of the system life cycle. The technical management unit addresses twelve competencies on the technical side of project management, and the professional unit covers the broader competencies of communication, problem solving, systems thinking and ethics.

Table 1: SPRDE-SE/PSE Competency Model

Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance

	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12 System Assurance
	13. Reliability, Availability, and Maintainability
Technical Management (12)	14. Decision Analysis
	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk Management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. SE Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

In general, competency models are used not only for workforce selection and development, but also for educational purposes. In particular, SE competency models are becoming more widely used in support of SE workforce development, education, and training[14-18]. This research task draws upon the SPRDE-SE/PSE competency model to define learning objectives for a set of courses being implemented across the 14 piloting universities.

Program Structure and Research Design

This pilot study is being implemented using a mixed methods approach in three sequential phases implemented over a 19-month period. Phase 1 (March 1, 2010-May 15, 2010) launched the Planning and Startup effort to identify the selection criteria and process for choosing the participating institutions and to identify the requirements each would need to implement as part of the research. These included a set of required, “common assessments” that would allow analysis of student outcomes across all projects, as well as project teams’ requirement to develop an actual product, prototype or other artifact based on a real DoD problem. A set of four problem areas was provided by the sponsor (Table 2).

Table 2

1. Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration;
   Portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources;
   Portable, low-power water purification;
2. An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use;
3. Develop modular, scalable, expeditionary housing systems that possess "green" electric power and water generation, waste and wastewater disposal, hygiene, and food service capabilities. Systems should be designed to blend in to natural/native surroundings and with minimal footprint;
4. Continued investigation and exploration into the realm of the possible with respect to “Immersive” training technologies. Objective is to flood the training audience environment with the same STIMULI that one would experience during actual mission execution. Where possible full sensory overload is desired much the same as experienced in combat. Specific S&T areas for development
   - Virtual Human. Successful modeling of emotions, speech patterns, cultural behaviors, dialogue and gestures.
   - Universal Language Model. The ability for trainees to seamlessly converse with the Virtual Human.
   - Virtual Character Grab Controls. The ability for exercise controllers to assume control of virtual characters.
   - Automated Programming. Cognitive learning models and the ability for exercise controllers to adjust virtual/live simulations.
   - Low cost wireless personnel sensors.
   - Sensors (i.e., lightweight vests) that facilitate physical stimuli (i.e., wounds, shots) to trainees.

Phase 2/Pilot Implementation (May 15, 2010-June 30, 2011) has focused on the development of course materials and customized assessments, implementation of the courses, and evaluation of the courses at the 14 piloting institutions. Implementation ranges from a one-semester “broad spectrum” introduction to SE course to a two-semester senior design course, to a supplemental independent-study approach that augments a traditional senior design course with SE modules.

During Phase 2, each of the institutions recruited student teams, organized the course structure (materials and faculty participation), identified and initiated collaborations with DoD and industry mentors who would serve in a variety of roles with student teams, developed and administered their own course assessments based on the learning objectives of their particular courses, and are delivering the courses.

Near the beginning of Phase 2, the DoD arranged an orientation session for SE Capstone faculty to meet DoD representatives to learn more about the authentic DoD problem areas being pursued in student projects. Problem sets were discussed and arrangements were made to structure the process for ongoing collaborations.

Key SE concepts to be assessed across all pilots are drawn from the SPRDE-SE/PSE Competency Model and include:

- Understanding and definition of the problem/need to be addressed by a systems solution including its context and related life-cycle aspects
- System definition (ConOps/System requirements), including the necessary trade-offs between conflicting requirements
- System architecture and design and the corresponding structural/technical trade-offs
- System integration, verification and validation including the trade-offs between coverage and available time and resources.

Phase 3/Analysis, Recommendations & Dissemination (July 1, 2011 – September 30, 2011) will analyze the results from all 14 participating universities and integrate them into a single set of observations to the sponsor about the effectiveness of the pilot programs, analysis of pre-/post learning of SE content, skills, and career interest, and the degree to which learning outcomes were achieved. It will also create a set of recommendations on how to scale-up the pilot program to be conducted across the U.S.

Currently in Phase 2, approximately 300 undergraduate and graduate students are or have been involved in SE Capstone pilot courses. To date, one university has completed the SE Capstone course and the remaining universities will conclude the pilot course at the end of the spring 2011 semester.

Research Design and Assessment Instruments

As part of the pilot, each university team was required to develop its assessments tailored to the specific learning objectives of its course. In addition, each university was required to administer three common assessments to all participating students.These would be used to gauge student learning of specific SE concepts and skills and would allow not only comparisons across universities but would provide data for correlating different outcomes with differences in implementation.

These assessments aimed to measure the following student outcomes:

- Understanding of what the discipline of SE is
- Understanding what systems engineers do
- Understanding the qualities and skills that systems engineers bring to projects
- Consideration of a career in SE
- Development and practice of the skills of systems engineering
- Understanding how systems engineers think (analytic skills)

As a condition of participation, all universities are required to administer three required, “common” assessments designed to measure SE learning, career interest, and awareness and interest in DoD problems and careers. In addition to these assessments, the research team is also collecting data from PIs and from DoD and industry mentors working with student teams.

The common assessments to measure student progress toward stated learning objectives were developed and are being administered to more than 300 undergraduate and graduate students during the 2010-11 academic year. These student assessments include:

(1) pre- and post-surveys to gauge knowledge of SE, interest in SE careers, and awareness of a spectrum of DoD SE problems;
(2) a pre- and post- case study analysis of an SE problem; and
(3) required weekly student blog posts to measure student progress toward more sophisticated SE analysis in the context of their own Capstone projects.

Data on course materials, course organization, customized assessments from participating universities, student demographics, and type of institution are also being collected and analyzed, as well as surveys from faculty, DoD mentors, and industry representatives.

Common assessment #1, the student survey, gathers information about students' backgrounds, interests, and prior experience with SE, asks them about their career aspirations, and then asks them five open-ended questions designed to assess their understanding of what SE is and of SE careers. The post-implementation version of this survey contains these five open-ended questions and also includes several satisfaction questions about the course. The five open-ended questions were:

- What is SE? Define it as best you can.
- In the context of SE, give an example of a system that would be addressed by a systems engineer.
- How might systems engineers differ from disciplinary engineers (mechanical, structural, etc.) working on a multidisciplinary team? Give an example.
- List five words that describe the skills and qualities that might be needed by a systems engineer.
- Name three engineering problem areas that you think are currently being addressed by the DoD.

The second assessment was designed to see the extent to which students had integrated SE concepts into their thinking by asking them to transfer that thinking to another situation. The students were presented with the story of the Bradley Fighting Vehicle, summarized and including a few short clips from *The Pentagon Wars*—an amusing fictionalized film version of the book by the same name. Students were asked to read and discuss the scenario and then respond individually to a single prompt: "Could the problems encountered in developing the Bradley Fighting Vehicle have been avoided? Explain your answer." We provided the faculty with a link to the results and encouraged them to use these to begin a discussion of the role of systems engineers in large-scale complex projects such as this. The same material was presented as a post-test, with the expectation that the responses would be more detailed and would show greater evidence of SE thinking after the capstone experience.

The third assessment was designed to provide a window into the progress of student learning during the course, including the SE competencies addressed. It required the students to write weekly blogs that summarized their experience for the week. The blog prompts were:

- What did you and your group accomplish this week?
- Which SE competencies best align with what you did this week?
- What specifically did you do in terms of each of the competencies you listed?

The blog posts were thus less of an assessment per se and more of a way to provide both the project team and the DoD advisors with information about project teams' progress. It was also hoped that the DoD advisors would use the blogs as one means of communicating with the students. The prompts for the final blog prompt, at the end of the course, were more elaborate and reflective. They were*:*

- What were the most important system-level trade-offs you had to consider during this project?
- If you were to start this project over again, what would you do differently?

However, the only school to complete the project in one semester and therefore the first to finish wanted the final blog to be more comprehensive and so replaced the above with the following set of questions, which we may ask the other projects to use as well:

- Do you feel that what you learned about SE benefited your capstone design project?
- Do you think SE provides a different approach to engineering design than what you were familiar with? Why or why not?
- Describe the advantages and disadvantages of working in multidisciplinary teams on a capstone design project. What tasks and processes were difficult for you to execute and what were you least prepared to deal with? Please explain.
- What advice would you give a peer on why it is important to take a course that incorporates SE principles within the context of a design project?
- Now that you have been introduced to SE principles and how they apply to a project, do you think you would like to have a career in SE? Why or why not?

In addition to the student surveys and other student assessments, several collections of data will be made throughout the courses from PIs and DoD and industry mentors.

Course Structures and Foci

A majority of the piloting universities relied on the expertise of SE faculty to lead or contribute to the conceptualization, development, and implementation of the program and course materials. Beyond this similarity, however, were many differences among the piloting universities, providing a diverse array of methods, approaches and structures for the implementation of SE Capstone courses. Table 3 summarizes the course structures, DoD problem area(s) addressed, students impacted, and other characteristics of the portfolio of 14 pilot projects.

Table 3				
Institution	**Course/ Project**	**Description**	**DoD Problem Area Focus**	**Students Participating**
Auburn University	SE in a Secure Computing Intensive Environment	1st course [Fall 2010] is a broad-spectrum overview to SE. It introduces major concepts using a case study of the security architecture of two open systems under consideration by DoD. 2nd course [Spring 2011] is an actual project employing low-cast, open-source, computing. The students will demonstrate secure collaboration using the Android open source software stack.	Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration. Course material for the 1st course will be delivered through presentations by speakers from industry and government; lectures, and interactive students activities. The 2nd course is a hands on sequel in which students will complete their Defense-focused capstone project	33 3 undergrads 30 grads Mix of CS, IE, and EE On-campus and distance education
Missouri S&T University	Agile Systems Engineering-Active and Experiential Learning Approach	1st Course [Fall2010]: Introduction to SE provides the student with basic understanding of main concepts, tools, and processes of SE. 2nd Course [Spring2011]: Physical Artifact Creation and Validation. Development of detailed	Immersive Training Technologies. Subtle simulation of real battlefield scenarios. Operational scenarios simulate getting shot, getting hit, and minor restriction.	10 undergrads 27 grads Mix of ECE, ME, and AE On-campus and distance education

		design for a wireless haptic vest with embedded sensors. Students will focus on the wireless tech to activate embedded sensors and mechanical components		
Penn State University	Interdisciplinary Capstone Design Project	This is a one-semester course/project [Fall2010]. Modules delivered by SE faculty. Projects are completed using the Bernard M. Gordon Learning Factory, a lab providing modern design, prototyping, and manufacturing facilities.	Expeditionary Assistance Kit. 1. Water purification system 2. Power generation from renewable energy sources 3. Local situational awareness system 4. Global low-bandwidth communication unit	17 undergrads Mix of BE, CE, EE, ME, IE
Southern Methodist University	Leveraging Interdisciplinary Teaching Environments to Research Immersive Training Environments	1st Course [Fall2010], students work in interdisciplinary teams to design an architecture solution that meets customer specifications. 2nd Course [Spring 2011], students will continue to work on interdisciplinary teams to build and test a prototype of their design.	Immersive Training. The objective is to improve existing capabilities in three areas: (1) fidelity of motion capture systems, (2) reduction of infrastructure required for team-based motion capture, and (3) high resolution facial expression capture and replication	11 undergrads Mix of CS, EE. and ME 3 PhD students contribute on course design and facilitation
Stevens Institute of Technology	Building Education and Workforce Capacity in SE	Implementation of SE in capstone senior design course [one year long]	Green-Expeditionary Housing. For a 100 person FOB and 3-6 months	24

	through Capstone Design	A series of 6 SE all-day workshops, are being delivered to introduce SE principles and methods to all students. Workshops take place every 4-6 weeks.	deployment. Modular housing with micro-grid support for alternate energy sources, including low impact solutions for waste and water	EM, ME, EE, CE, Civ Eng, A&T
University of Maryland	Special Topics in SE	This is a one semester course that is offered twice over one academic year. The goal of both graduate and undergraduate pilots is to introduce students to SE via a hands on project experience	Focuses on low-cost, low-power computers leveraging open source technologies. Supports integrated wireless sensor networks, vehicle bus, and black box	15 undergrads From all engineering departments
University of Virginia	Extensible SE Capstone Experience for Non-SE Seniors	It exposes students to the entire SE process. This will be accomplished via two interdisciplinary capstone projects over one academic year. During the 2nd semester the two teams will test and evaluate each other's projects.	(1) This project involves Immersive Training Capability, Combining Sensors, Actuators and Virtual Environ to Track Hand and Finger Position (2) This project will develop a robust decision support system for rapid of water supply and sanitation technologies for HA/DR operations.	19 undergrads from all engineering departments 2 SE grad students serve as TAs.
Wayne State University	Integrated Material Design and Realization for	This project integrates SE product development concepts across 4 courses at	Expeditionary Operations. The projects will be focused on	30 Mix of ME, IE

	HA/DR Kits	the undergrad and graduate level. 1 Full semester course (Winter 2011) plus modular insertion into multiple other courses (start process – Sept 2010)	development of elements of HA/DR kits, such as solar oven, water purification system, alternative energy	and SE
Air Force Institute of Technology	Introduction to SE Process and Design	This course [one academic year] provides a broad introduction to a systematic approach necessary for the formulation, analysis, design and evaluation of complex systems.	Low-power computing for operations in austere environments. Development of a novel hybrid electric UAV for near silent, long loiter, low energy operations.	5 grads Mix of AE, SE
Naval Post-Graduate School	Transforming Graduate Education in SE	A series of 8 core SE courses [one academic year] in the master's curriculum are being taught in a faculty team-based pedagogy, with the capstone project integrated into the entire curriculum as a carry-through, hands-on experience. The courses provide a holistic span of education from systems thinking, quantitative analysis, through system design and production	Expeditionary Operations and HA/DR Assistance Kits. Development of novel, low density power supplies, advanced materials with low thermal and visibility properties, low signature communication devices.	25 grads SE
US Air Force Academy	Capstone Design Project	This project integrates sequentially two SE courses over one academic year.	Low Power Computing A 10 KVA solar energy system for	7 undergrads

		Students will learn to successfully work in a multidisciplinary team, to apply SE and management tools, communicate project details, and evaluate contemporary military issues	deployed operations. The end system will incorporate smart grid technology to facilitate control and integration	Mix of EE, CE
US Naval Academy	Principles of Engineering Systems Design	The senior design capstone course [one academic year] is enhanced with additional SE sections based on experimental coursework. This is an independent study course based on Defense Acquisition University courses	Expeditionary Ops. Portable, low power water purification. Portable, renewable power generation, storage and distribution	16 undergrads Mix of EE, CE, NA, OE
US Military Academy at West Point	Systems and Engineering Management Design	This capstone course [one academic year] emphasizes SE in technology-based organizations. Cadets examine interconnections between planning, organizing, leadership, control, and the human element in production, research and service organizations	Immersive Training Augmented Reality: synthetic environ, decision analysis for optical & video displays, high fidelity tracking	4 undergrads Mix of SE, EM, and OR
US Coast Guard Academy	SE Capstone Enhancement	This course [one academic year] incorporates critical elements of SE. Cadets will have regular contact with	Expeditionary Ops. Green Power Generation HA/DR Portable hull inspection system.	54+ undergrads Mix of Civ Eng,

		external customers [USCG Shore Maintenance Command and USCG Aviation Logistics Center] and must defend their work at preliminary and final design reviews	Green electric power in remote hot climates. In water remote propeller cleaner. Hybridization system for fleet vehicles.	EE, and ME

NOTES:

1. Sources include proposal documents submitted by universities, first progress reports, and a summary prepared for the 2010 Annual SERC Research Review conference Nov. 9-10, 2010.
2. The number of students shown in the table above include only those who are directly involved in the entire SE Capstone course [coursework +project].
3. Abbreviations :
   EM: engineering management, CE: computer engineering, Civ Eng: civil engineering, EE: electrical engineering, NA: naval architecture, OE: ocean engineering, AE: aerospace engineering, A&T: arts and technology, OR: operations research, IE: industrial engineering, ME: mechanical engineering, CS: computer science, SE: systems engineering, BE: biomedical engineering

Preliminary Observations and Lessons Learned

An interim report was submitted by each piloting university in January 2011. The following section summarizes the progress, status, and preliminary observations/findings based on, in all but a few cases, the mid-point of course implementation.

The key features that differentiated the organizational structure of the programs at the different Institutions of Higher Education (IHEs) were the following:

- Faculty: The collaboration of two or multiple faculty members on course design and implementation. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinarity of a SE team. SE faculty were the largest percentage of participating faculty.

- Courses: The integration of the SE component into existing courses or the creation of entirely new courses.

- Course sequencing: The implementation of a course sequence that included an introductory course followed by a capstone experience or a capstone experience only.

- Student population: The involvement of either undergraduates or graduate students as learners[1] or a mixed class with both undergraduates and graduate students.

- Mentors: The presence and level of active and meaningful involvement of DoD and industry mentors in a variety of student learning experiences.

The ultimate measure of effectiveness of the course design will be determined by the student outcomes identified as project goals:

- Increase student learning of SE competencies
- Increase student interest in DoD problems/careers
- Increase career interest in SE study and careers

It is premature at this stage of course implementation to correlate student outcomes with the structure or content of the courses or with any particular strategies or course materials. However, the PIs' interim reports provide some insights into preliminary lessons learned about course objectives and implementation. These observations fall into several categories:

1. Challenges teaching the broad topic of SE to non-SE majors under time constraints.
2. Challenges with equivalent grading policies in multi-disciplinary teams, particularly where SE was an overlay to an existing multi-disciplinary team structure.

[1] Some institutions engaged graduate students as teaching or technical assistants, but here we are referring to graduate students who are participating in the course for credit.

3. Challenges with content-domain-specific problem areas and with finding meaningful ways for other disciplinary majors to contribute.
4. Motivating external mentors to bring authentic professional experiences to the learning experience and sustaining that involvement over time.
5. SE content modules provide opportunities to bring non-SE majors to a common understanding. These have been implemented with varying frequency, durations, and numbers across several projects.
6. Where possible, the integration of Defense Acquisition University modules provide additional incentives for students to gain desirable certifications, but scheduling common experiences for students to take these modules impacted completion.

In some cases, the challenges identified were common to the formation and operation of effective, multi-disciplinary teams.

7. Provide subject matter expertise (internal and external) to infuse sufficient disciplinary knowledge such that students may focus on the bigger SE competencies.

DoD Problem Area Addressed

Figure 1 illustrates each university's choice of one or more problem areas based on existing faculty expertise and interest. Two civilian universities and one service academy chose to work in more than one of the DoD problem areas. More than half the projects (8) addressed DoD Problem Area 1 (low-cost/low-power computers); Problem Area 4 (immersive training technologies) was the next most popular choice; with the remaining two areas divided among the other partner institutions:

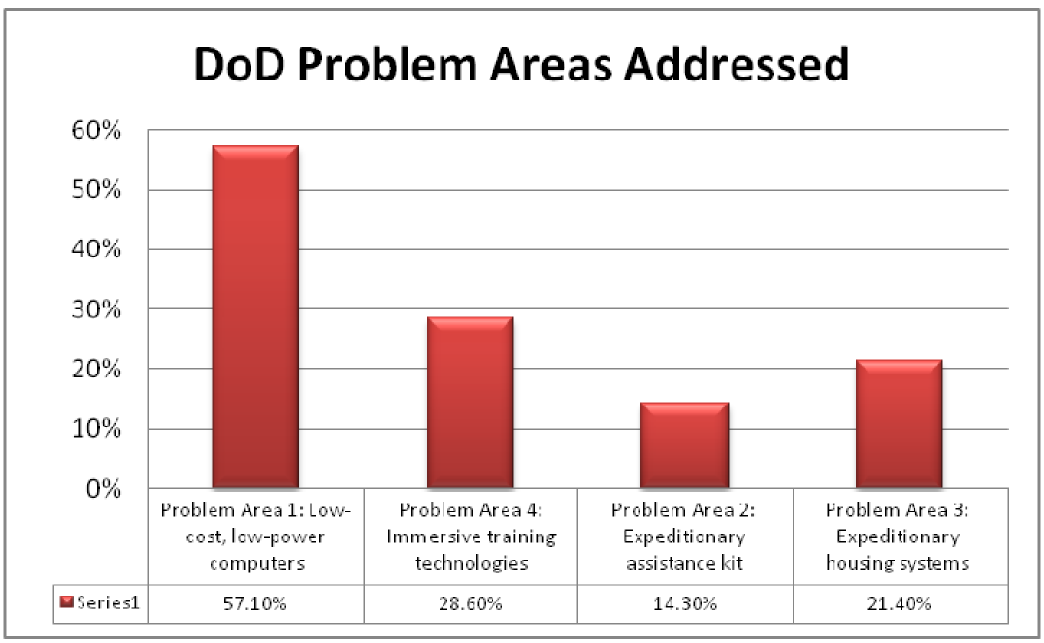

Figure 1

Problem areas were chosen because faculty members with expertise in a particular area were available and interested; because the problem area was considered to have human interest or related to a social concern and would therefore attract students; or because the institution had ongoing projects in that area. Only one PI reported a concern about working on a DoD problem, and that was only from one student.

Faculty Involvement

A majority of the universities relied on the expertise of SE faculty to lead or contribute to the conceptualization, development, and implementation of the program, but many other faculty were involved as well, particularly from mechanical engineering and computer science. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinarity of an SE team. Figure 2 represents the percentage of the 14 pilot universities that included those types of disciplinary faculty in the RT-19 project:

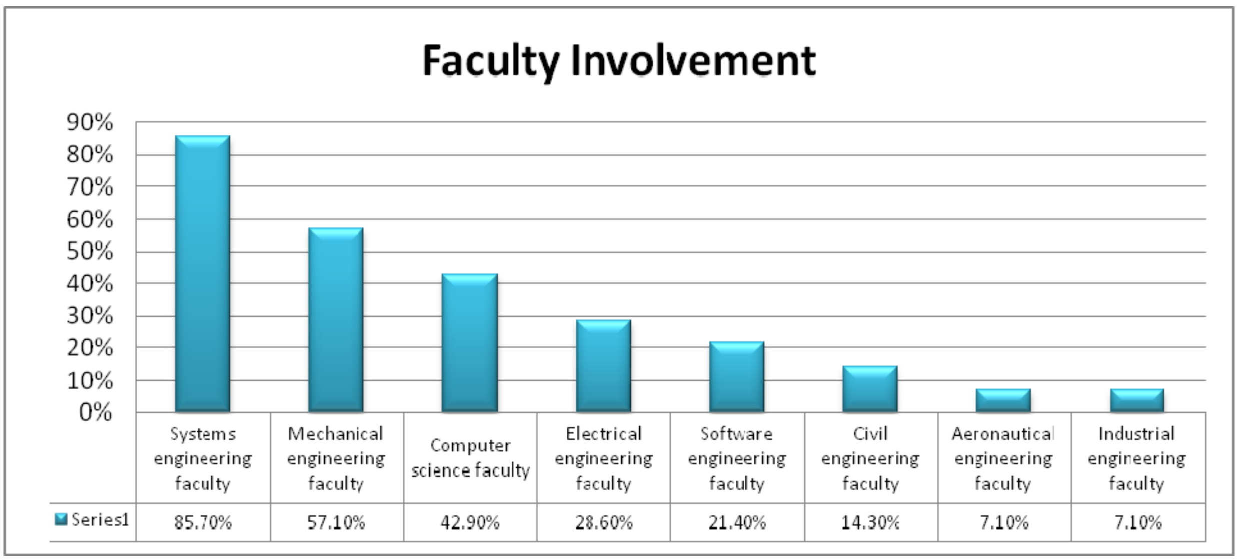

Figure 2

As indicated in Figure 3, nearly two-thirds of the fourteen projects were planned and implemented by teams of two or three faculty members, but four projects included four or more faculty. Only one institution developed a capstone course that was planned and taught by a single faculty member:

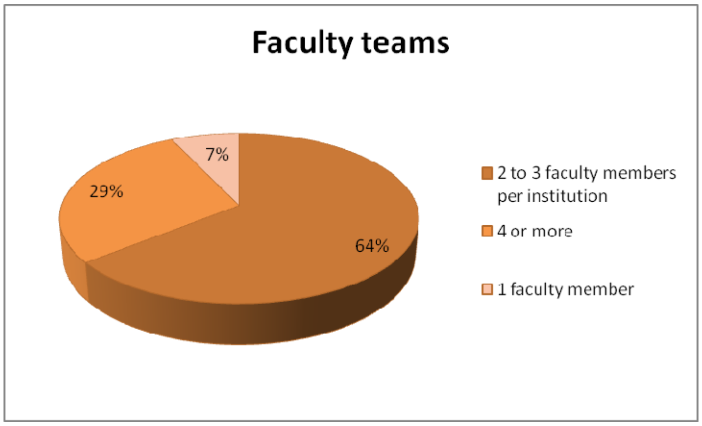

Figure 3

Faculty took on different roles, including that of classroom instructor, curriculum developer, project advisor, and SE subject matter expert, with some being several of these. Figure 4 represents the percent of all faculty in the project where faculty could play more than one role.

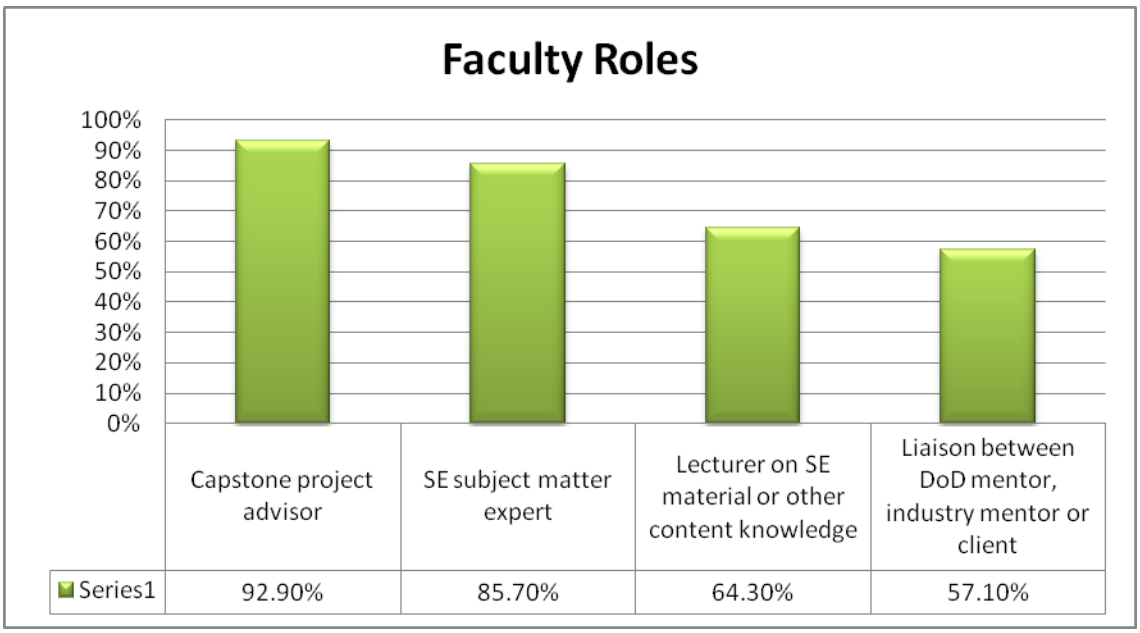

Figure 4

Course Sequences, Structures, and Types of Student

There was a diverse array of methods, approaches and structures for the implementation of the courses. The table on the following page summarizes the differences in type of student (graduate/undergraduate/both), course integration, and type of course sequence.

	Students: Undergraduates/ Graduate	Integrated into Existing SE Courses	Intro course + Capstone/ Capstone only
Auburn University	U	N	I/C

Missouri S&T University	U/G	Y	C
Penn State University	U	Y	C
Southern Methodist University	U	Y	I/C
Stevens Institute of Technology	U/G	Y	C
University of Maryland	U	Y	C
University of Virginia	U	Y	C
Wayne State University	U/G	Y	C
Air Force Institute of Technology	G	Y	I/C
Naval Postgraduate School	G	Y	I/C
US Air Force Academy	U	Y	C
US Naval Academy	U	Y	C
US Military Academy	U	Y	C
US Coast Guard Academy	U	Y	C

All but one institution integrated the RT-19 effort into existing SE courses, with only Auburn developing a completely new course. Thirteen of the 14 projects were structured into two semesters, with only one institution (Penn State) conducting a single-semester capstone project course. However, one (University of Maryland) is conducting two one-semester capstone courses (i.e., with different students). Those who carried over two semesters did so in one of two ways: (1) The first semester was an introduction to fundamental SE concepts and processes and the second was devoted to the development of the capstone design project or (2) both semesters were devoted to the capstone project work.

Student Teams

The student population also varied in terms of the mix of graduate students and undergraduates, as illustrated in Figure 5. Nine of the institutions had only undergraduates as students, two had exclusively graduate students and three had a mix. In addition, two institutions had graduate students acting as teaching assistants or providing technical help. Student teams ranged from four to seven members. Teams met during class, at lab sessions at some institutions, and also communicated through a number of non-face-to-face channels, including e-mail, telephone, videoconference, weblogs, and on 16 collaborative document sharing platforms. Teams generally submitted weekly progress reports and prepared final project presentations. At two institutions, student teams included distance students who communicated with their teams via their university Blackboard portal or the Stevens project-wide Sakai site. In half the universities, students chose their own teams; in the rest, faculty did so.

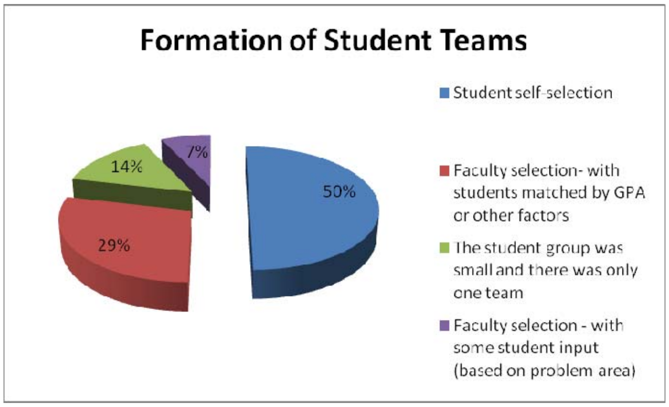

Figure 5

Figure 6 shows that over 75 percent of all capstone student teams were mixed in discipline, allowing faculty and students to experience working in a context resembling that of professional systems engineers:

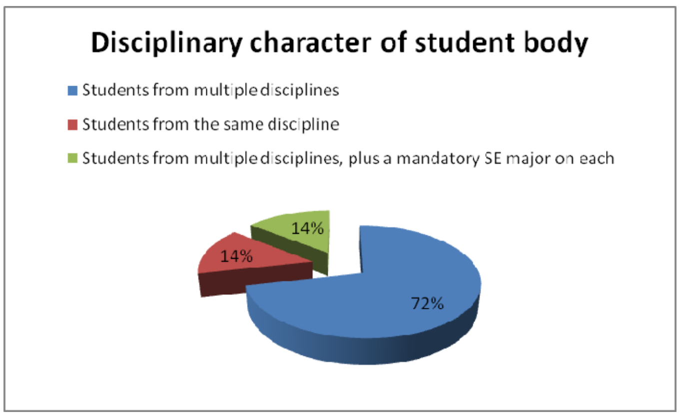

Figure 6

<u>Student Characteristics</u>

The total number of students returning surveys was 294. Of those, 127 were undergraduates, 124 were graduate students, and 11 were postgraduates. While the total number of undergraduates and graduate students was nearly equal across the 13 institutions, a closer look at differences between individual institutions shows that nearly half of the 13 were comprised entirely of undergraduates, as illustrated in Figure 7. Four institutions had graduate students (including postgraduate students) and the remaining three had mixed undergraduate and graduate populations. However, the ratio varied.

Class sizes varied widely across institutions, ranging from a low of 3 or 4 students to 48. The average class size was 20 (median = 17, SD = 14).

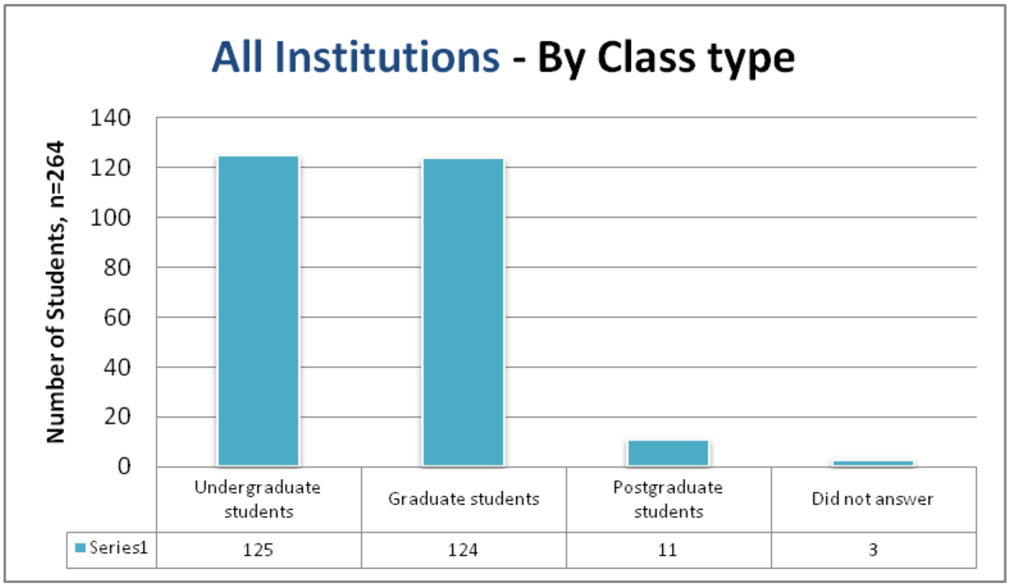

Figure 7

Figure 8 illustrates that most of the undergraduates were in their senior year and most of the graduate students were in their first year.

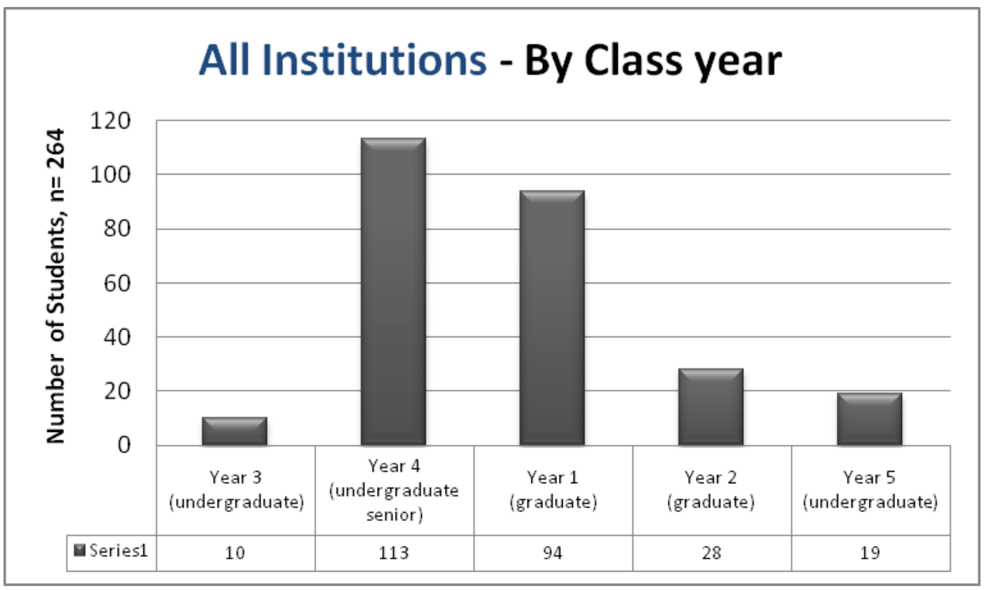

Figure 8

The most prevalent engineering discipline among students across all institutions, as illustrated in Figure 9, was SE followed by Mechanical Engineering, Electrical Engineering, Computer Science/Software Engineering, and Industrial Engineering.

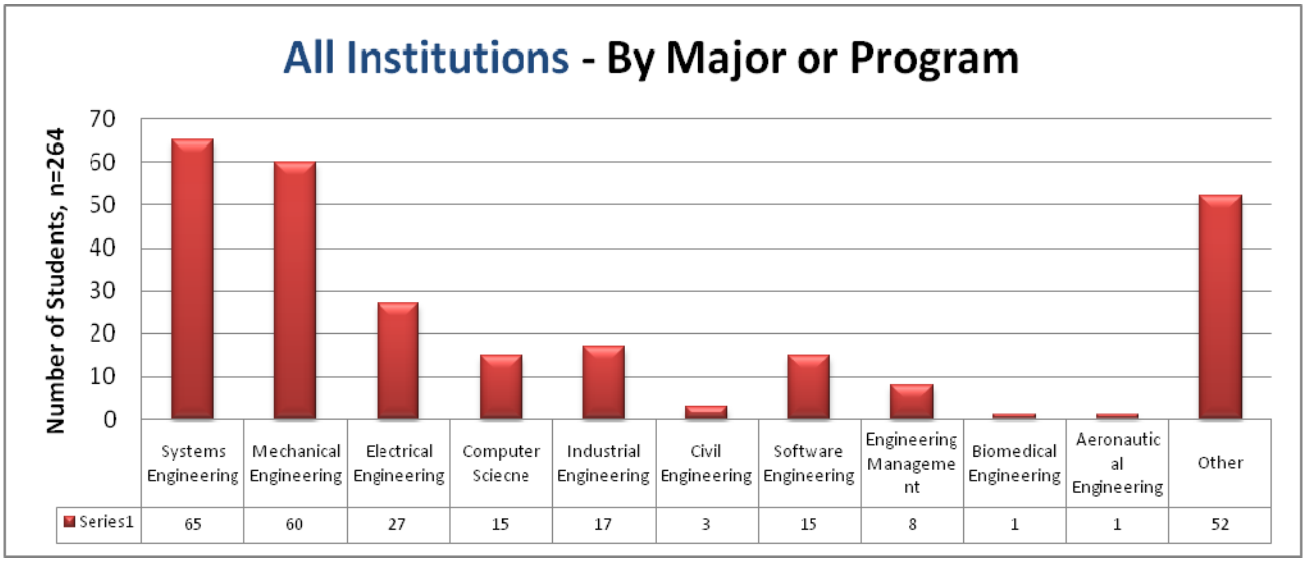

Figure 9

Overall, the student population (n=264) was over three-quarters male (77 percent), with a small female population (16 percent) and a small percentage of students selecting not to report their gender (7 percent). Figure 10 shows the gender of the student population.

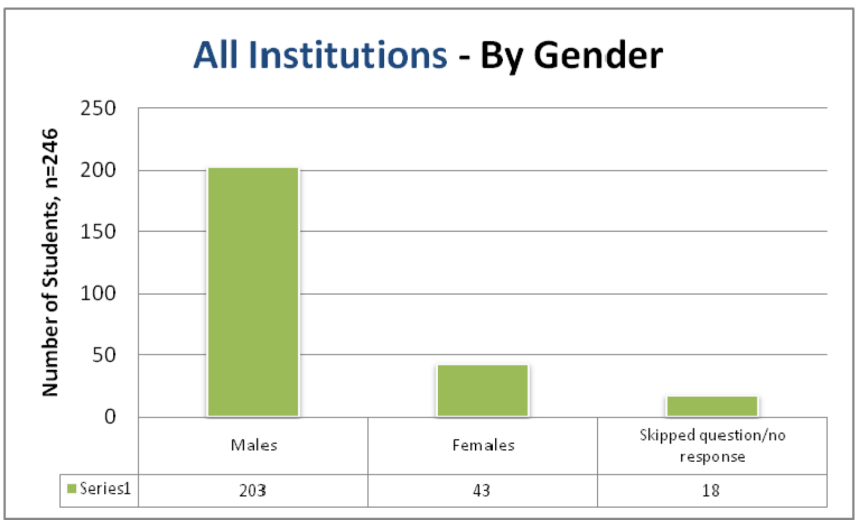

Figure 10

As illustrated in Figure 11, students' reported ethnicities (n=264) were: White (64 percent); Asian (11 percent); Black or African-American (7 percent); Hispanic/Latino (5 percent); Hawaiian or Other Pacific Islander (>1 percent); and unreported (11 percent).

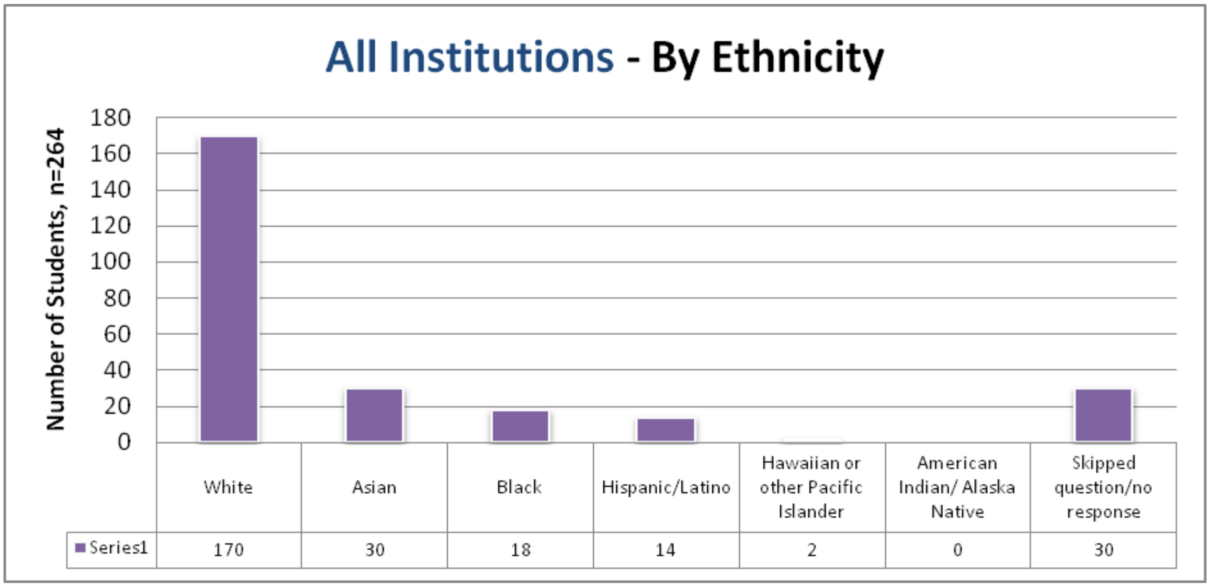

Figure 11

Interest in SE as a Career

In the pre-survey, less than half (41 percent) of all students reported a high level of interest in becoming a systems engineer, while 18 percent reported moderate interest and 25 percent reported little interest; 15 percent were not sure (Figure 12).

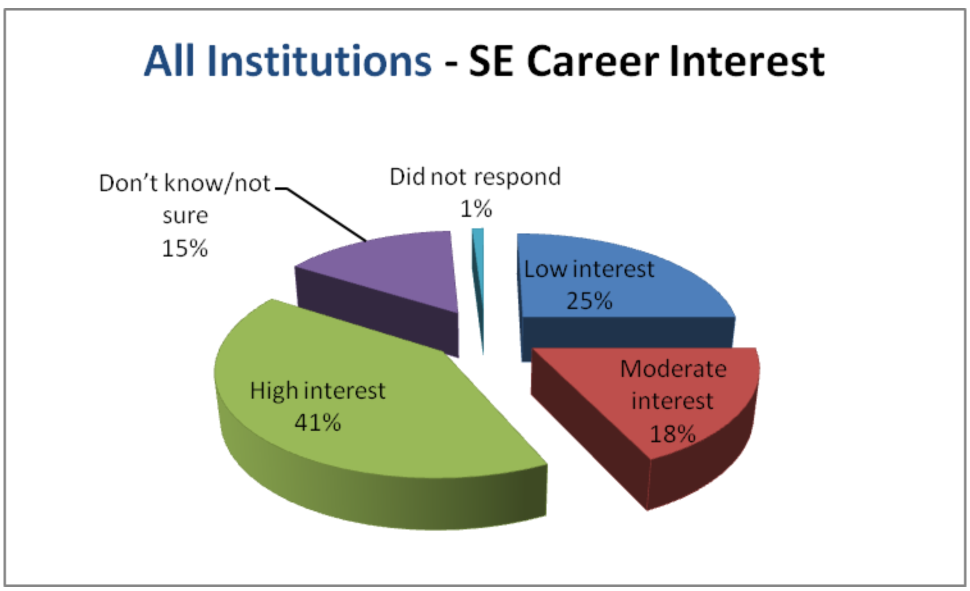

Figure 12

Working for the government as a systems engineer

Approximately the same percentage (45 percent) of the students reported they had a high interest in working for the government as a systems engineer, while 20 percent said they had a moderate

interest and 19 percent said they had little interest in doing this; 13 percent were not sure (Figure 13).

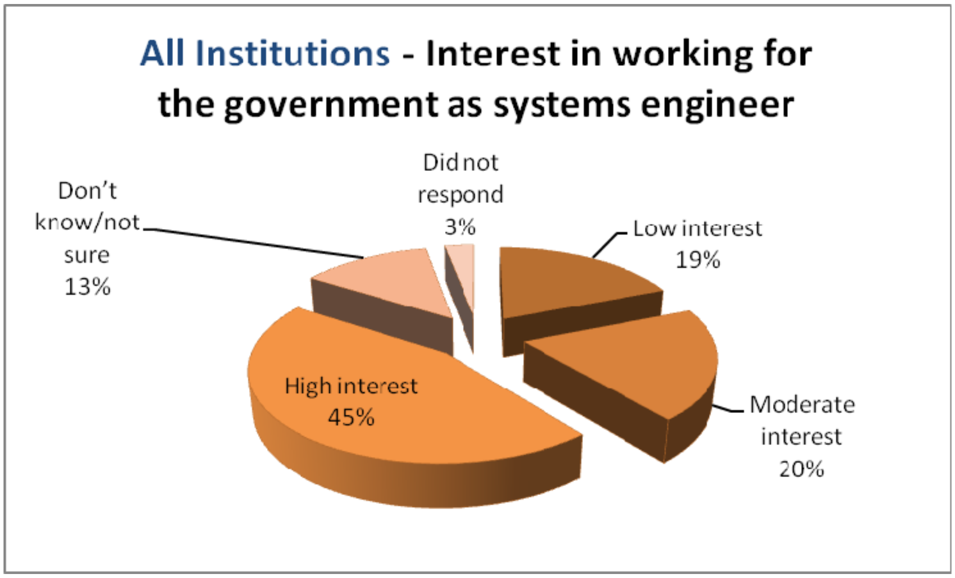

Figure 13

DoD Mentors

Among the PIs who had collaborations with DoD mentors, very different levels of interaction with them were reported as indicated in Figure 14. Despite efforts on the part of the DoD, several had not been assigned or connected with projects at the time of submission of the interim reports. Thus while over 43 percent of the PIs reported that their DoD mentors were "very involved," another 50 percent reported not having a mentor or not yet working with their mentor:

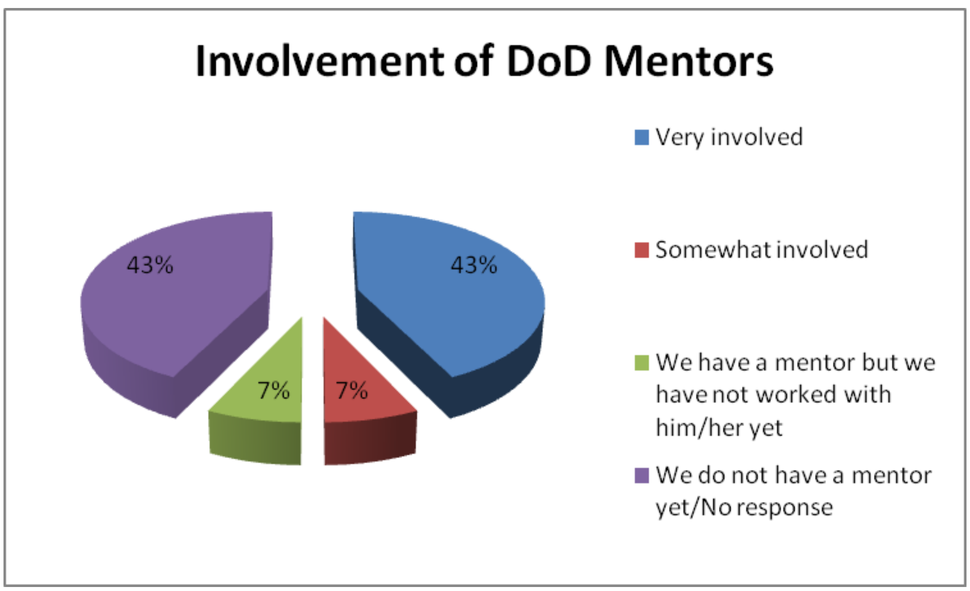

Figure 14

Some PIs reported that their mentors were playing an "active role in meeting…by phone, email and VTC," while others reported that the mentor had not followed up with the students after some initial communication. Of the PIs who had mentors, one-third reported that the DoD mentors communicated at least weekly (one even reported daily interaction), 22 percent reported that they communicated bi-weekly, and 45 percent reported they had communicated at least several times a semester (Figure 15).

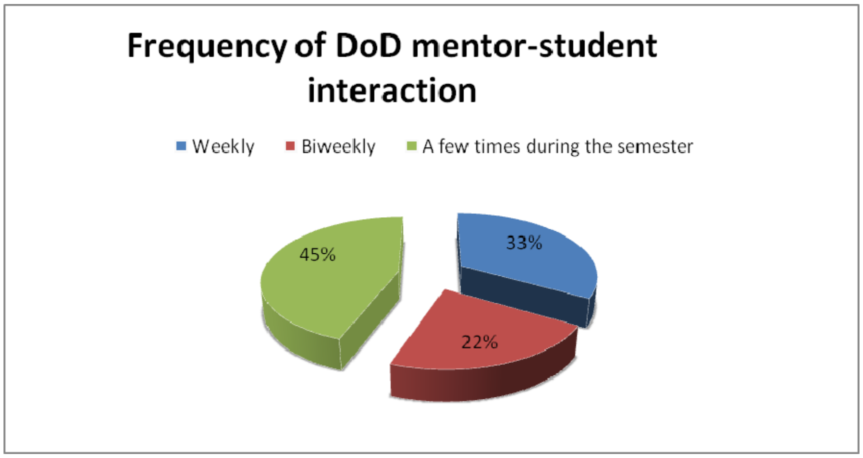

Figure 15

Like RT-19 faculty, DoD mentors facilitated student learning in a variety of ways; however, their roles differed instructionally depending on whether they also served as clients, as they did for 50 percent of participating institutions. Some of their roles included:

- Providing feedback on student projects and deliverables
- Providing technical expertise
- Attending student presentations
- Facilitating field trips offsite to manufacturing or design sites where students could observe engineering processes related to their projects

Mentors with the highest level of student engagement interacted with students in every single activity area and with frequency, while others provided only intermittent correspondence. Note that mentors could engage in more than one kind of interaction. Figure 16 represents the level of Mentor-Student Interaction.

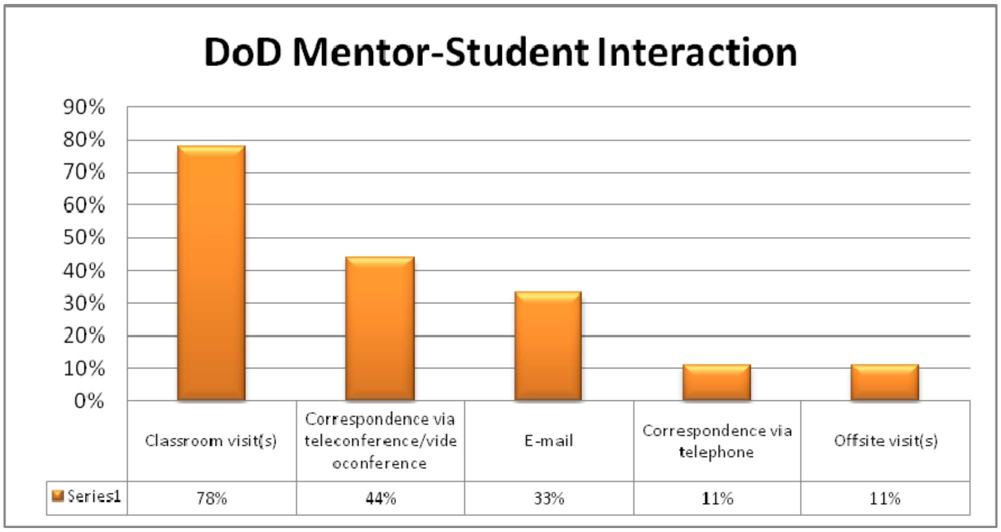

Figure 16

As illustrated in Figure 17, the PIs therefore differed in their evaluation of the mentors' contributions to student learning and engagement. Note that mentors could make contributions in more than one area:

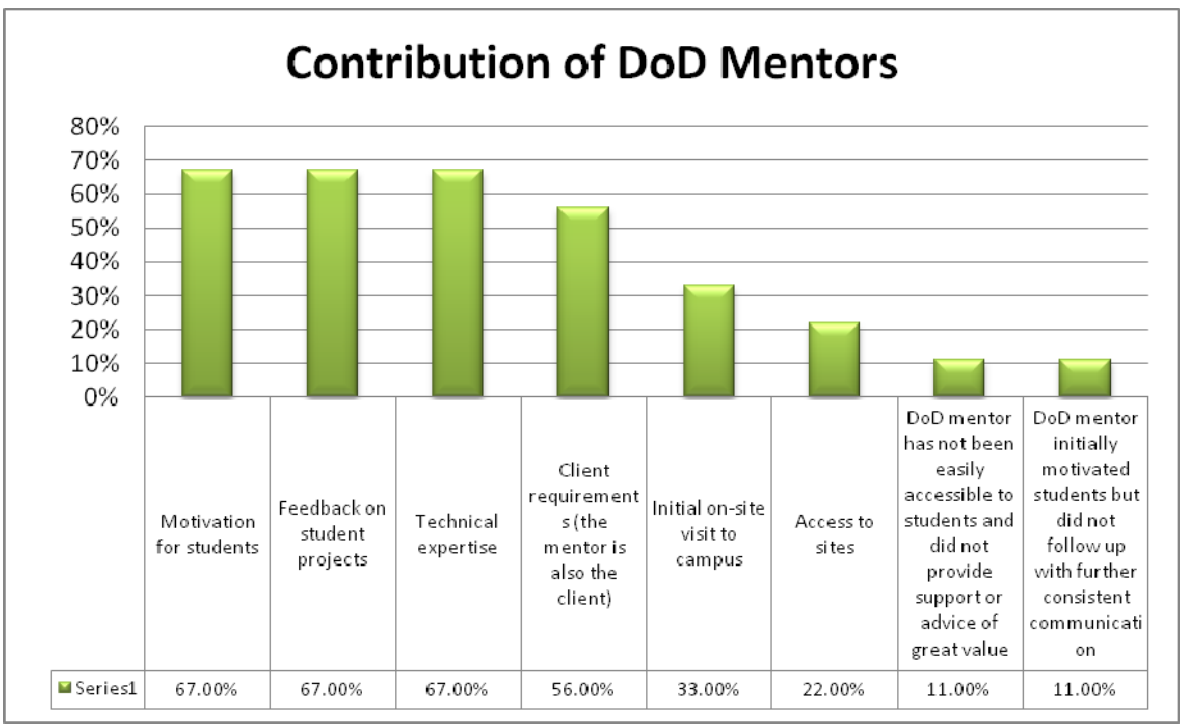

Figure 17

Industry Mentors

About 60 percent of the PIs reported not having an industry mentor. Three of the eight who did not have industry mentors reported that they planned to work with one during the spring semester (Figure 18).

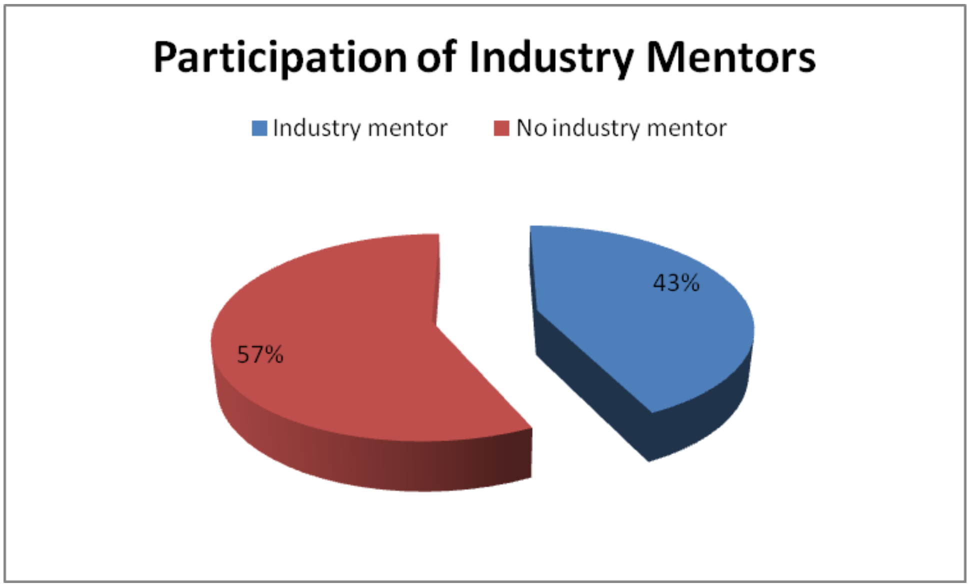

Figure 18

Industry mentors took on roles similar to the roles played by DoD mentors—as clients, consultants, or SMEs. Note that mentors could play more than one role:

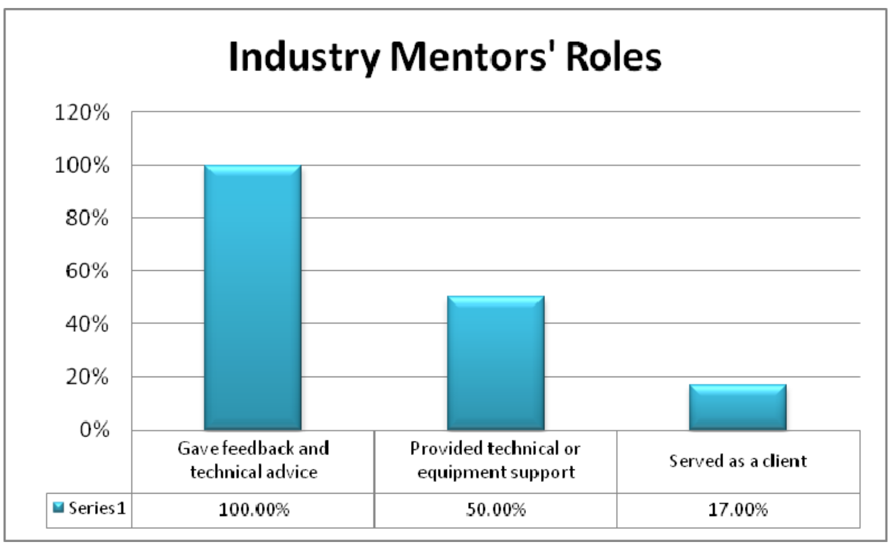

Figure 19

PIs at two institutions that had both industry and DoD mentors reported that having both types of mentors benefited the students' projects. For example, one PI reported that the DoD mentor acted as a client while also offering occasional help with analysis and understanding system requirements, while the industry mentor acted as a consultant "educating [students] on their technical approach." The other PI whose team included both types of mentors described the industry mentor as "part of the project teams…intimately involved with [students'] day to day progress and project management aspect," compared with the DoD mentor, who took the customer's perspective and dealt more with design and engineering concerns.

At another institution, however, a PI expressed dissatisfaction with the mentor's overlapping roles of client and project advisor/consultant and argued for better defined responsibilities. Initially regarded by students as a "customer" or "major stakeholder," the DoD mentor functioned in reality as a subject matter expert who assisted students with the design process.

Discussion

It is premature at this stage of course implementation to report on student outcomes with the structure or content of the courses or with any particular strategies or course materials. However, the PIs' interim reports provide some insights into preliminary lessons learned about course objectives and implementation. These observations fall into several categories:

1. Challenges teaching the broad topic of SE to non-SE majors under time constraints.

2. Challenges with equivalent grading policies in multi-disciplinary teams, particularly where SE was an overlay to an existing multi-disciplinary team structure.

3. Challenges with content-domain-specific problem areas and with finding meaningful ways for other disciplinary majors to contribute.

4. Motivating external mentors to bring authentic professional experiences to the learning experience.

5. SE content modules provide opportunities to bring non-SE majors to a common understanding. These have been implemented with varying frequency, durations, and numbers across several projects.

6. Efforts to provide specific disciplinary expertise (internal and external) to infuse sufficient content knowledge into student teams such that students are able to focus on the bigger SE competencies.

It is also not clear at this stage the extent to which external funding has created entirely new materials or simply (and in some cases, substantially) enhanced existing courses. This is an area for further investigation.

Next Steps and Future Research

As indicated throughout this paper, the preliminary observations and findings represent only a snapshot of the richness of the 14 SE Capstone courses that have been and are being implemented by pilot institutions in most cases, mid-way through the implementation of their courses. At this point, no comprehensive analysis of student learning has been conducted at this stage of course implementation. Further analysis and later papers will aim to connect the course content and organization, including materials created by faculty as well as the contributions of external mentors, with impact on student learning of SE content, their interest in SE careers, and their interest in DoD problem areas and careers.

As noted, this research has been undertaken in order to inform the development of a larger capacity-building and scale-up effort that could substantially increase the SE workforce available to DoD and industry in the next decade and beyond. This research will capture methods, strategies, and tools that have led to desired student outcomes. Further research to translate these findings into methods, tools, and processes that can be operationalized in new universities has been proposed. Anticipating a scale-up effort involving additional universities (n=20-100), the lessons learned from the SE Capstone Project may be applied across a diverse set of institutions, with varying capacity in SE.

Acknowledgement

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